

Major fishery events in Kerguelen Islands: *Notothenia rossii*, *Champscephalus gunnari*, *Dissostichus eleginoides* – Current distribution and status of stocks

by

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ABSTRACT. - The large-scale trawl exploitation targeting virgin stocks of marbled notothenia (*Notothenia rossii*) off the Kerguelen Islands occurred after the discovery by the Soviet Union scouting fishing fleet of the fishing grounds in the early 1970's. The fishery shifted to icefish (*Champscephalus gunnari*) and grey notothen (*Lepidonotothen squamifrons*) when overexploitation on the shelf and surrounding banks resulted in the sharp decline in the catches of marbled notothenia. The creation of the French EEZ in 1978 closed the free fishery but did not stop the reduction of the biomass of exploited stocks. The SKALP first surveys (1987 and 1988), despite bias in the protocols, revealed the poor state of biomass in these shelf stocks. Only the icefish fishery maintained a series of strong cohorts with harvestable biomass, which eventually declined and lead to its closure in the 1990's. However, the more recent biomass survey (POKER, 2006) showed no recovery in these stocks. Possible changes between species (predators-prey relationships, ecological niche) and in the marine environment may have contributed to the decline of stocks. Only one species, the Patagonian toothfish (*Dissostichus eleginoides*), of which deep-sea stocks have been naturally protected at the beginning of 1990. It maintained a high amount of biomass despite a strong IUU fishing episode from 1997-2004. The management of the stock needs to consider the migration patterns of the species over the Plateau and outside. The analysis of fish distribution during the historic fishing period (1970-2010) shows permanent aggregations by species in specific and different areas of the shelf. This knowledge contributes in conserving vulnerable stocks, while providing opportunity to consider marine protected areas.

RÉSUMÉ. - Les événements majeurs concernant la pêche aux îles Kerguelen – Distribution actuelle et statut des stocks : *Notothenia rossii*, *Champscephalus gunnari* et *Dissostichus eleginoides*.

La découverte par la flotte d'exploration de pêche de l'Union soviétique dans les années 1970 d'un stock vierge de colin de Kerguelen (*Notothenia rossii*) a conduit à une pêcherie au chalut de grande ampleur sur les fonds de pêche au large des îles Kerguelen. La pêcherie se convertit ensuite à celle du poisson des glaces (*Champscephalus gunnari*) et du colin austral (*Lepidonotothen squamifrons*) quand la surexploitation du plateau et des bancs environnants conduisit à une diminution sévère des captures. La création d'une ZEE française en 1978 a marqué l'arrêt de la pêche libre mais n'a pas contribué à celui de la réduction inexorable de la biomasse des stocks exploités. Les campagnes d'évaluation SKALP (1987 et 1988), en dépit de biais dans les protocoles, ont révélé l'état critique de la biomasse de ces stocks du plateau. Seul le poisson des glaces possédait encore des cohortes de biomasse importante qui déclineront par la suite. Les pêcheries de ces espèces furent successivement fermées dans les années 1990. Cependant la plus récente évaluation de biomasse (POKER, 2006) ne montre pas de récupération notable de ces stocks et de possibles changements dans les relations entre espèces (relations prédateurs-proies, niches écologiques) et dans l'environnement peuvent s'être ajoutés au déclin de ces derniers. Une seule espèce la légine australe (*Dissostichus eleginoides*), pour laquelle le stock profond a été naturellement protégé jusqu'au début des années 1990, possède toujours une importante biomasse en dépit d'un épisode important de pêche INN (1997-2004). La gestion de ce stock nécessite de prendre en compte les échanges dus aux migrations sur l'ensemble du Plateau et avec l'extérieur. L'analyse de la distribution des poissons sur la période historique (1970-2010) révèle que les concentrations propres à chacune des espèces sont permanentes dans des aires spécifiques du plateau. Ceci peut contribuer à aider à la conservation des stocks vulnérables et permet d'envisager de considérer des zones de protection marines.

Key words. - Kerguelen I. - Southern Ocean - Fisheries - *Notothenia rossii* - *Champscephalus gunnari* - *Dissostichus eleginoides*.

HISTORY OF THE KERGUELEN FISHERY

The Kerguelen fishery started in 1970-1971 and has continued since, except for one year (1978-1979) of no fishing activity, with the creation of the French Exclusive Econom-

ic Zone (EEZ). These 40 years of fishing resulted in a total reported catch of 924 000 t (Fig. 1) and probably, an additional catch of about 40 000 t (estimated removal from illegal, unregulated and unreported (IUU) fishing episode from 1997-2004). Removals before the creation of the French

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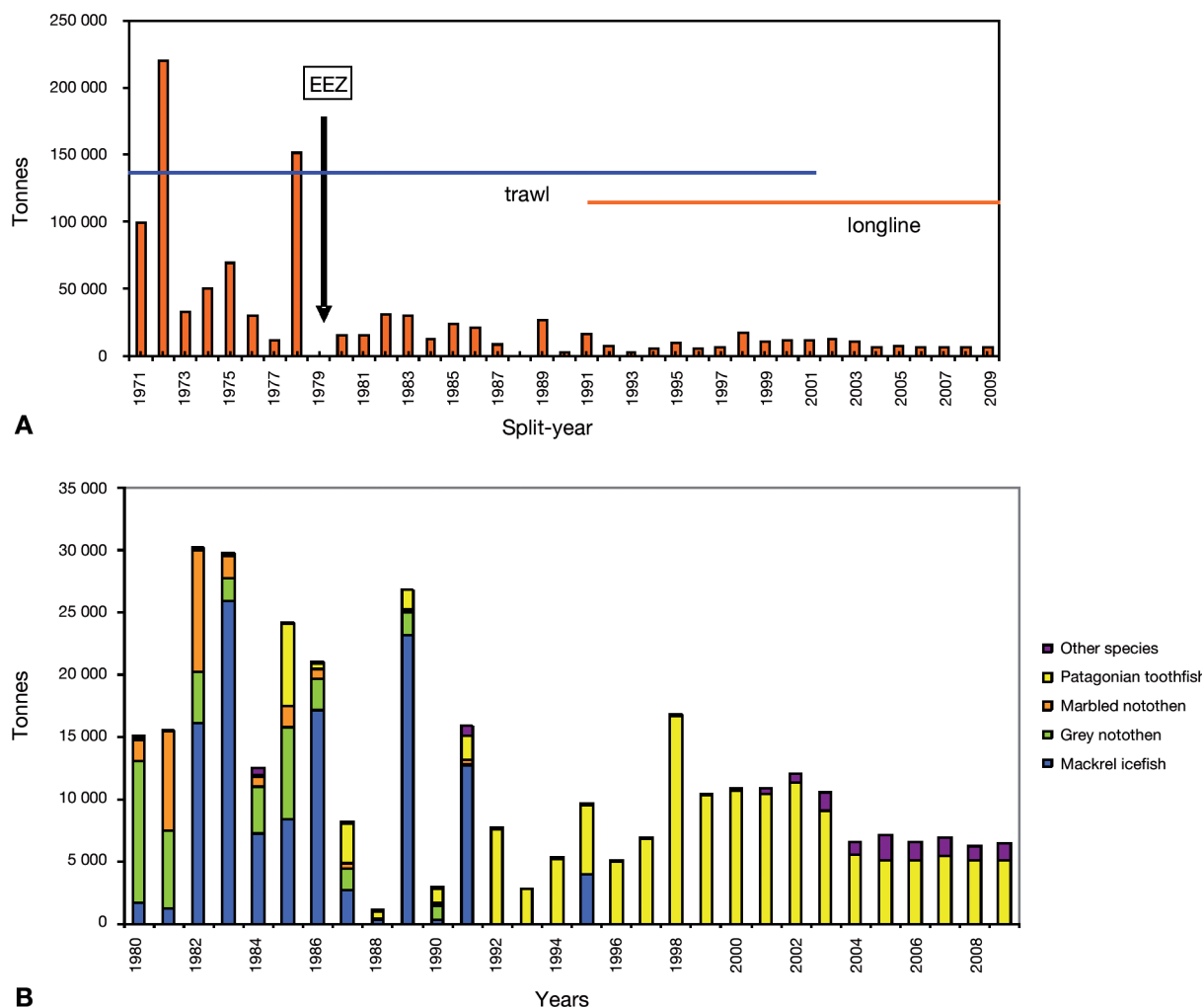


Figure 1. - Historical fishery catches, trawl and longline, off the Kerguelen Islands. **A**: Total; **B**: Split by species since the establishment of the French EEZ. Note: the 1997-2004 IUU fishing catches of Patagonian toothfish are not reported.

EEZ must be considered cautiously since reports were not fully reliable.

The largest catches (unregulated) have been registered before the creation of the EEZ (Hureau and Duhamel, 1980). Deep-freezer trawler fleets invaded the Kerguelen Plateau and harvested the virgin stocks. Limitations in catches, fishery controls, statistical and biological monitoring (fishing logbooks, observers on board vessels) were enforced only with the establishment of the EEZ. This also included major changes in the fishery, such as the recognition of target species, use of fishing technology, and market demand. Global positioning system (GPS), net sensors, gears design, doors, winches and weather forecasts have helped the fishing masters in this isolated area, barely mapped and known for its very rough seas. During the last decade, significant episodes occurred such as the shift from trawling to longlining and a genuine increase in the market price of Patagonian toothfish.

The time series of catches: marbled notothen → mackerel icefish → Patagonian toothfish

The catch data on the Kerguelen Islands shelf belong to the CCAMLR Statistical Sub-division 58-5-1 (including the totality of the French EEZ) and the time series can be divided in periods of 10 years.

The first period is from 1970/71-1979/80 (Fig. 2), dominated by the marbled notothen (*Nototothenia rossii*). The USSR factory trawlers discovered the virgin stock and overexploited both the feeding grounds on the shelf and the winter spawning area on the south-eastern slope. In this period, an unrestricted foreign fishery exists and huge catches have been reported during these early years of exploitation (CCAMLR Statistical Bulletin, 1990).

As the catches declined, the trawlers shifted to other available species such as the grey notothen (*Lepidonotothen squamifrons*), and to a greater extent, mackerel icefish

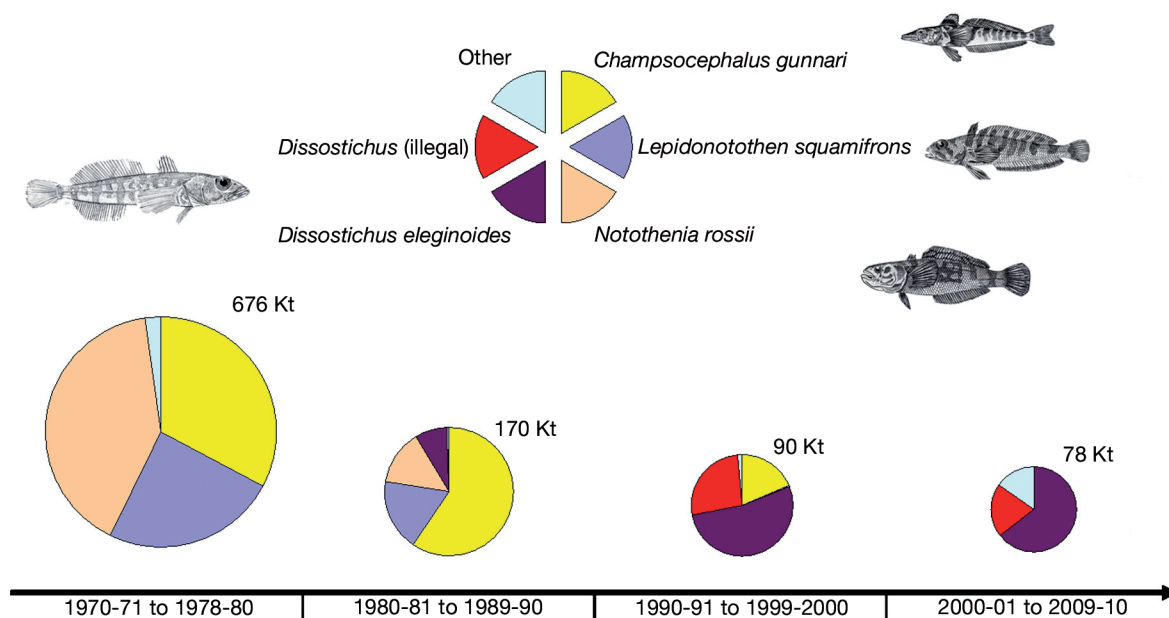


Figure 2. - Proportion of species in the catches of the Kerguelen Islands' fishery for four decadal period (from Duhamel *et al.*, 2005, modified). Note that the level of total catches varies between graphs.

(*Champsocephalus gunnari*). This was done with the help of scouting vessels tasked to search new fishing grounds and discover fishing aggregations on the shelf (Duhamel and Hureau, 1981). The second period, from 1980-1989, began with the creation of the EEZ and the establishment of the first fishing regulations. Initial trials of French trawlers occurred in this decade.

The third period, from 1990-1999 is highlighted by the discovery of the slope Patagonian toothfish (*Dissostichus eleginoides*), where aggregations were first fished by trawlers (both French and Ukrainians) then longliners (Ukrainian).

The last period, from 2000-2009, showed the development of the exclusive deep-sea French longline fishery still targeting the Patagonian toothfish with by-catch of grenadiers and skates species.

The knowledge of the species and the fishery

Few published scientific data were available on the Kerguelen shelf fishable stocks before the EEZ. Only the fishery related Polish expeditions 1977-1978 (Slosarczyk and Wysocki, 1980; Sosinski, 1981) on the Kerguelen Plateau, Japanese reports of various cruises (JAMARC, 1977, 1978) and some information from the whaling industry (Yukhov, 1972, 1982) were available. However, the YugNIRO (Kerch, Crimea) reports of the Soviet Union fishery remained unpublished.

Soon, after the beginning of the EEZ an observer program has been created by French authorities in 1979 to collect biological data (measurements, biological samples,

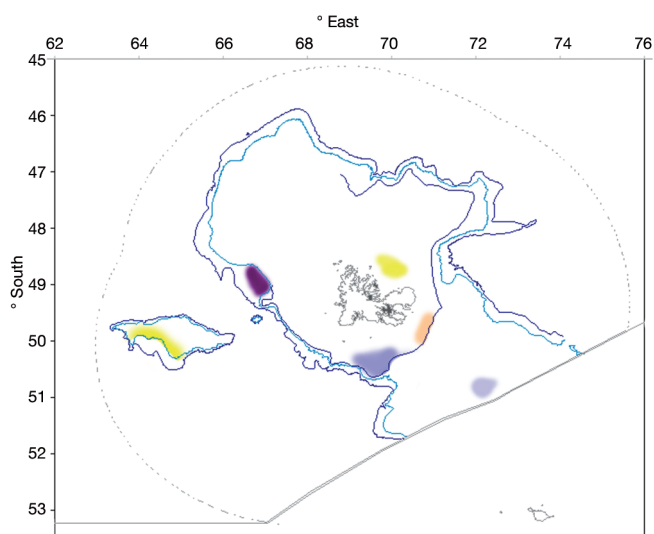
by-catch observation, tagging) and statistics (logbooks) on board the fishing vessels to monitor the fishery (Duhamel, 1995a). Presently, data collection for all fishing activities is 100% covered. An additional control of weighing landed catch has been introduced in recent years. A major step in monitoring was the setting up of the KERPECHE fishery statistical database, the first one (1980) for the Southern Ocean fishery (predating CCAMLR) (Duhamel, 1987c).

To add, several surveys have been conducted to better understand the fishery: in 1987-1988 joint Soviet-French trawl fishery surveys (SKALP) with *Skiff* and *Kalper* working on a grid of trawl stations on the shelf and surrounding banks (Duhamel, 1993); in 1996 joint Japanese-French longline investigation with *Anyo-Maru 22* on the slope and deep-sea area targeting toothfish; and in 2006, the first French fish biomass survey POKER with *Austral* performed random stratified trawl sampling for all species biomass (Duhamel and Hauteceur, 2009).

The main results of these studies (monitoring of fishing activities and dedicated scientific cruises) were to establish the life cycle, distribution and abundance of key species (growth, maturity, fecundity, mortality, diet, knowledge of feeding and spawning areas, movements between areas and depth) (Duhamel, 1981; Duhamel and Hureau, 1985; Duhamel and Ozouf-Costaz, 1985; Kock *et al.*, 1985; Duhamel, 1987a, 1987b, 1987d, 1991, 1995b). A more comprehensive view of the level of fish species in the ecosystem from benthic and pelagic relationships in the food webs was obtained (Tab. I). Results proved that the fish aggregations were geographically and bathymetrically distinct by species,

Table I. - Trophic relationships between fish, pelagos and benthos on the Kerguelen Islands shelf (data from Duhamel *et al.*, 2005).

Level	Species	Main diet
Top predators	<i>Dissostichus eleginoides</i>	Fish, cephalopods, euphausiids/hyperiid amphipods
	<i>Channichthys rhinoceraus</i>	Fish, euphausiid/hyperiid amphipods
	<i>Notothenia rossii</i>	Fish, Cnidaria, Ctenaria, euphausiid/hyperiid amphipods
	<i>Lepidonotothen squamifrons</i>	Tunicata (Salps), Cnidaria, Ctenaria, euphausiid/hyperiid amphipods, fish
	<i>Lepidonotothen mizops</i>	Euphausiid/hyperiid amphipods, Cumacea, Mysidacea
Plankton feeders	<i>Champscephalus gunnari</i>	Euphausiid/hyperiid amphipods, fish
	<i>Mancopsetta maculata</i>	Amphipods (Gamarid), Mysidacea
	<i>Bathyrja murrayi</i> & <i>B. eatonii</i>	Isopods, annelids (Polychaetes), fish
	<i>Gobionotothen acuta</i>	Annelids (Polychaetes), amphipods (Gamarid), Mysidacea
Benthic feeders	<i>Zanclorhynchus spinifer</i>	Ophiurids, Cumacea, Mysidacea

Figure 3. - Known spawning grounds for the main exploited fish in the Kerguelen Islands area. Yellow: mackerel icefish *Champscephalus gunnari*; Green: marbled notothen, *Notothenia rossii*; Blue: grey notothen *Lepidonotothen squamifrons*; Violet: Patagonian toothfish *Dissostichus eleginoides*. (modified from Duhamel and Hureau 1990).

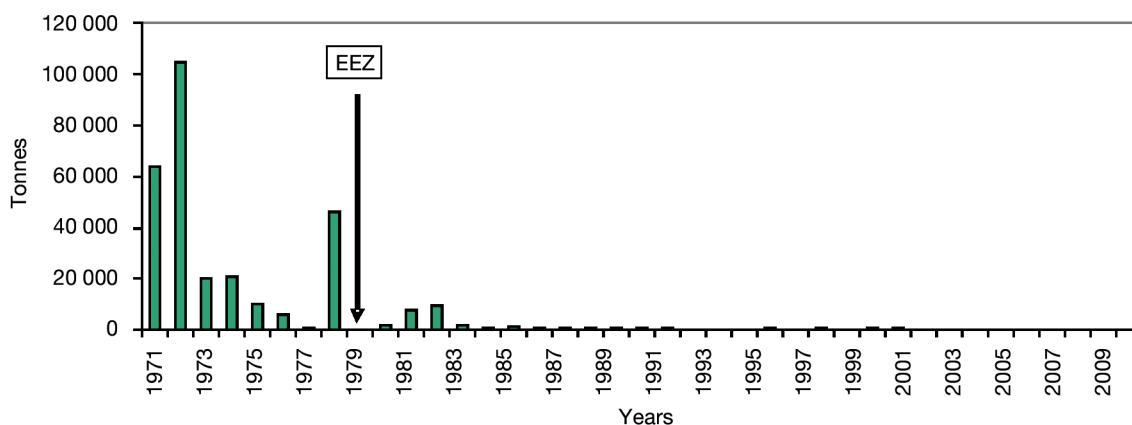
and spawning grounds do not overlap for the main abundant species (Fig. 3). SKALP (1987-1988) and POKER (2006) surveys showed evidence of stability with time, targeted or not, of adult fish.

A synthesis on the three major target fish species in the Kerguelen Islands area follows.

The marbled notothen *Notothenia rossii*

This species reaches a maximum size of about 90 cm (10 kg), with a life time of about 15-16 years. The full description of the life cycle came from South Georgia (Burchett, 1983), with a first pelagic 'blue phase', the use of kelp (*Macrocystis pyrifera*) marine forests as nurseries during a juvenile 'brown phase' and an adult distribution across the whole shelf and surrounding banks. Annual spawning migrations of the adult stock occur at the Kerguelen Islands during winter on a single spawning ground on the south-east shelf break (350-450 m) (Duhamel, 1981, 1982, 1987a, 1987b). Market value is strongly reduced by high concentrations of encysted nematodes inside the flesh (Duhamel *et al.*, 2005).

This first targeted species on the Kerguelen shelf was

Figure 4. - Historical catches of marbled *Notothenia* (*Notothenia rossii*) off the Kerguelen Islands (arrow indicates the EEZ establishment).

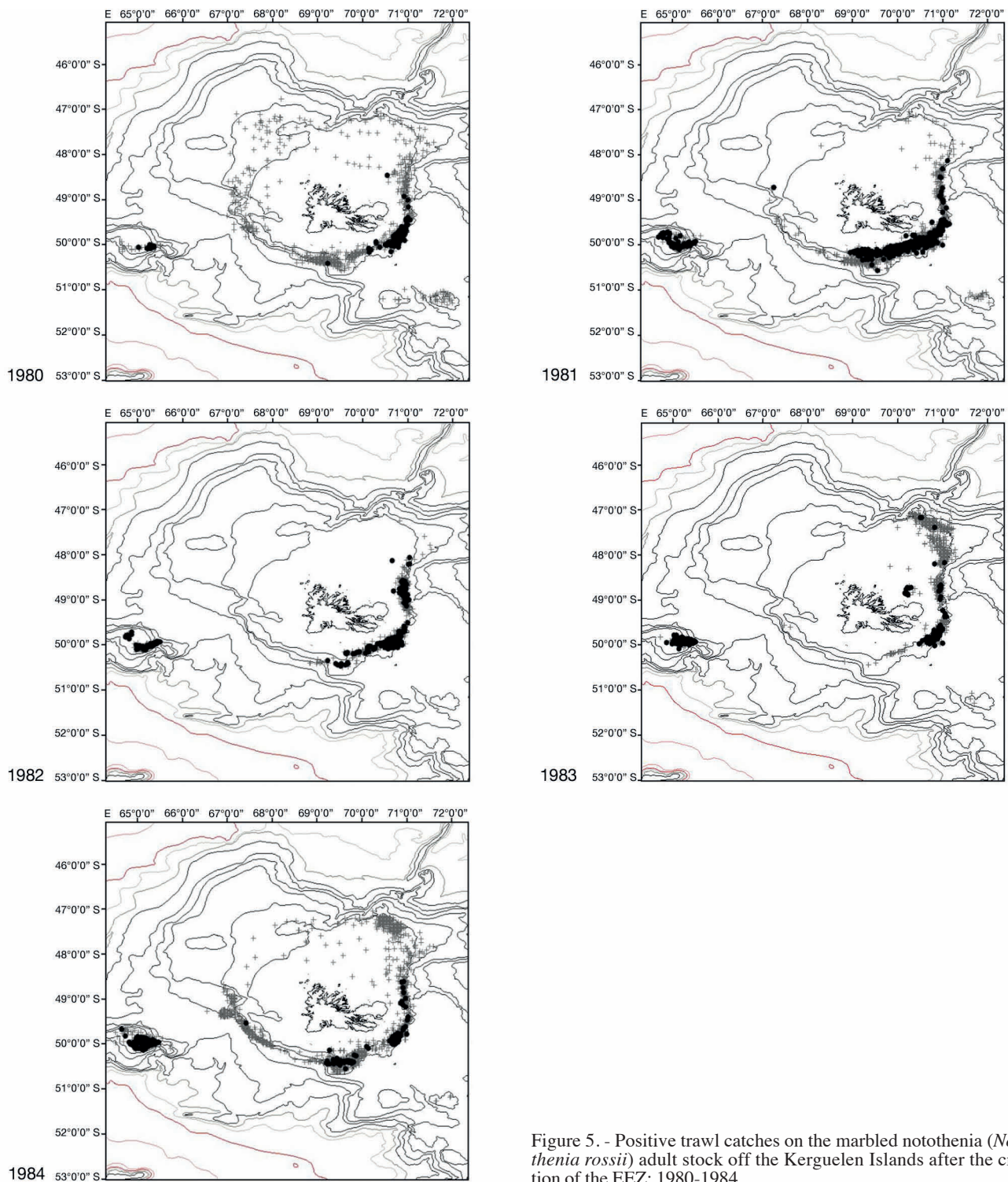


Figure 5. - Positive trawl catches on the marbled notothenia (*Notothenia rossii*) adult stock off the Kerguelen Islands after the creation of the EEZ: 1980-1984.

highly abundant in the beginning. Annual catch reached its maximum during the second year of exploitation in 1971-1972 (Fig. 4) with 105 000 t (taken from a virgin stock), but the lack of data on this major fishing effort (period prior to EEZ establishment) does not permit the description of the

full evolution of the fishery on this stock. Posterior catches for the period 1980-1984 showed a winter fishery on the spawning hot spot and some by-catch on the offshore western Skif bank (during the icefish target autumn fishery) (Fig. 5). Virtual population analysis results (Duhamel,

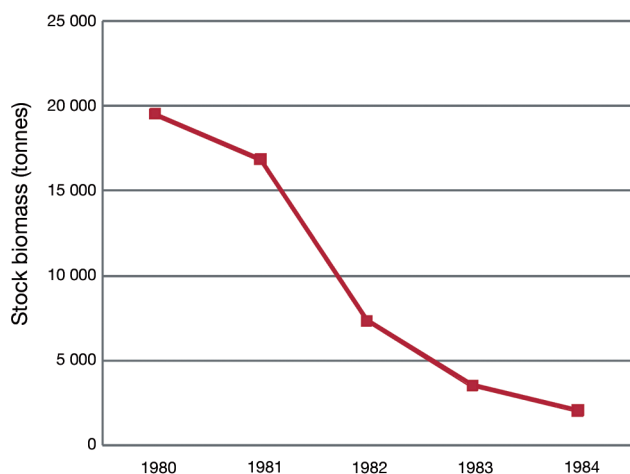


Figure 6. - Trends in the biomass of the marbled notothenia (*Notothenia rossii*) after the Kerguelen Islands EEZ establishment (from Duhamel, 1987d).

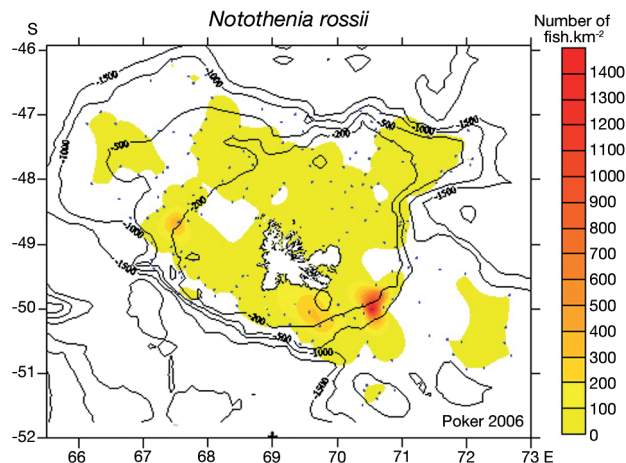


Figure 7. - Current distribution of the marbled notothenia (*Notothenia rossii*) sub-adult/adult stock during POKER biomass survey cruise off the Kerguelen Islands (from Duhamel and Hauteceur, 2009).

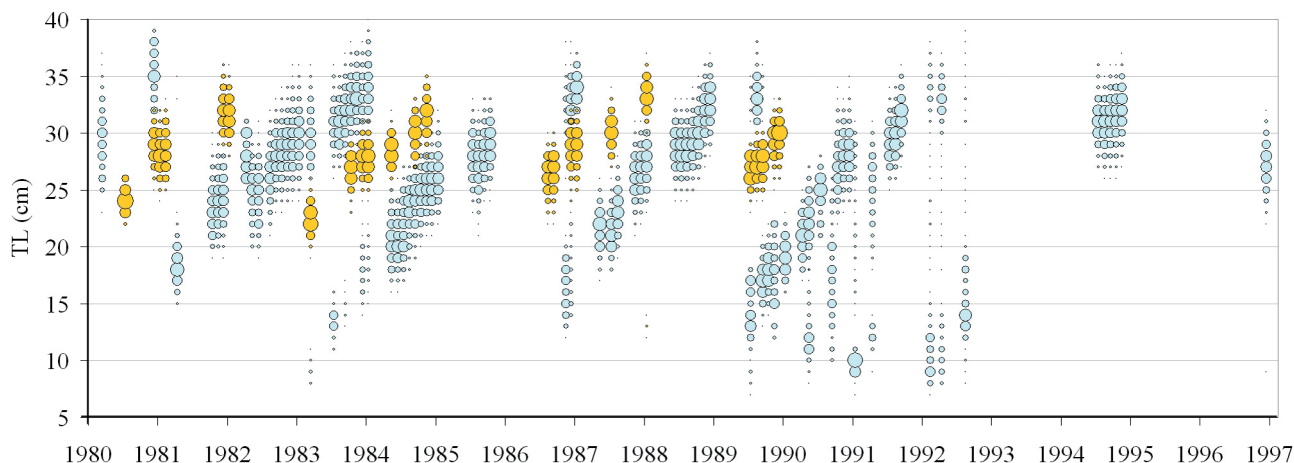


Figure 8. - Observed 1980-1997 time series of length frequencies distributions (LFD) for mackerel icefish (*Champscephalus gunnari*) on the north eastern shelf (blue) and Skif bank (orange) fishing grounds off the Kerguelen Islands (adapted from Duhamel, 1991).

1987d; Fig. 6) lead to the closure of the fishery in mid 1980's to avoid the stock to collapse. First estimates indicated a low level of biomass (Duhamel, 1988). The more recent evaluation (Duhamel and Hauteceur, 2009) showed that this biomass remained low at less than 10 000 t with a current distribution similar to the previously known (Fig. 7). Actual recovery rates are however unknown. The present status reinforces the current conservation measures in place for this stock, which is the prohibited fishing of protected and targeted species.

The mackerel icefish Champscephalus gunnari

This small species (45 cm maximum size on the Kerguelen shelf, 0.5 kg) is a typical semi-pelagic shallow-depth fish exhibiting an exclusive zooplankton diet (crustaceans:

euphausiids, hyperiid amphipods). It is also a short-living fish with a life cycle of five to six years, with strong year-classes (cohorts) which appear every three years. Two stocks seem to occur in the Kerguelen Island with distinct annual abundance cohorts (Fig. 8), spawning grounds and periods: the north-eastern shelf stock spawning in the inshore system of submarine canyons (Baleiniers Gulf) in early winter; and the Skif Bank stock spawning on the bank's slope in autumn (Duhamel, 1987d, 1991, 1995b; Duhamel *et al.*, 2005). A biomass survey showed different use of space according size for a stock (Fig. 9).

Declared annual catches of mackerel icefish were around 10 000 t before EEZ, except in 1971-1972, 1974-1975, 1977-1978 where they reached 40 000 t and more. After EEZ creation such high amounts were never achieved (Fig. 10). The

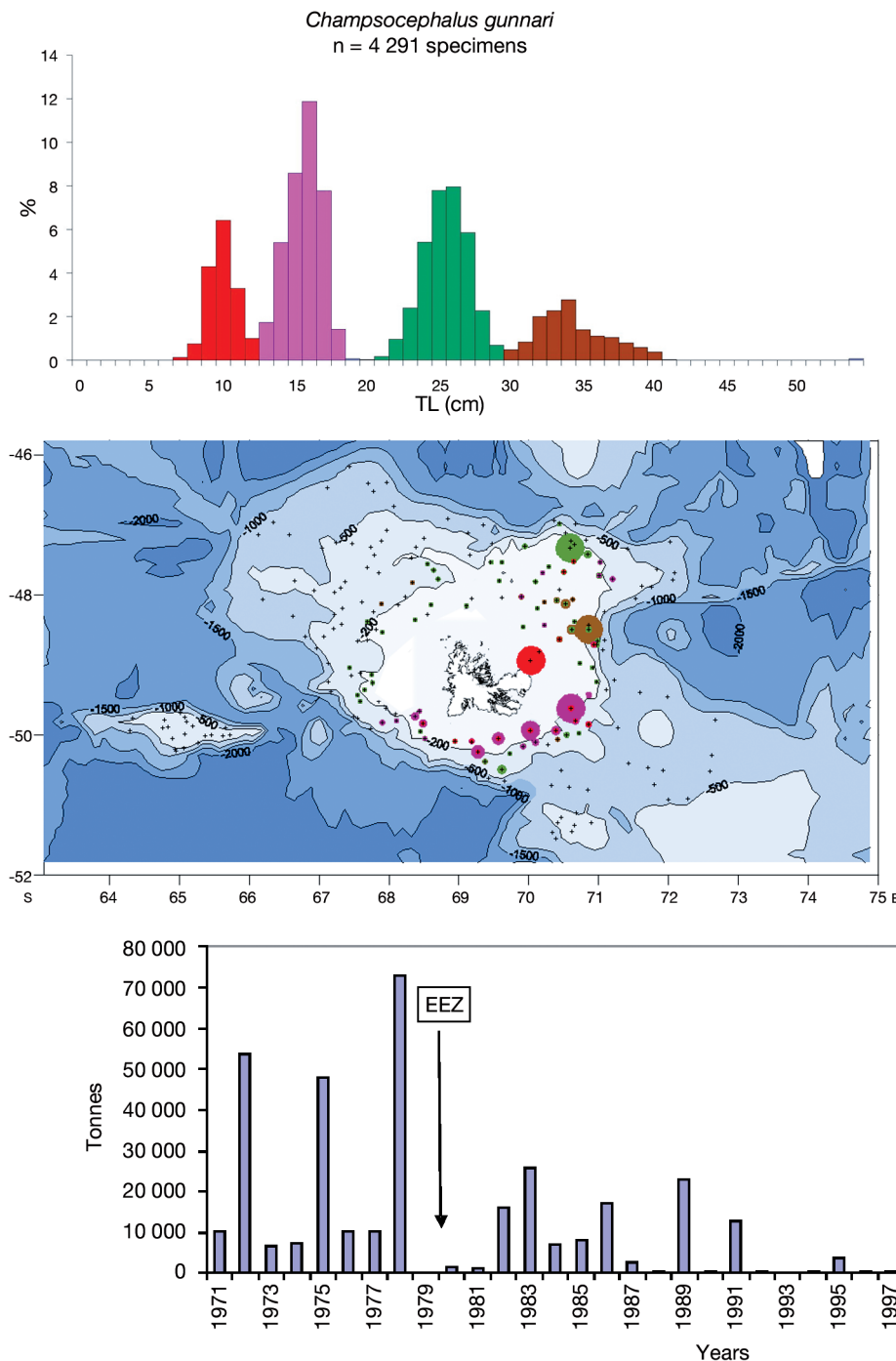


Figure 9. - Geographical distribution of mackerel icefish (*Champsocephalus gunnari*) by modal size groups on the Kerguelen Islands shelf (red: first modal peak; purple, second; green: third; brown: largest fish) observed during POKER biomass survey cruise (2006). (upper box: LFD)

Figure 10. - Historical catches of mackerel icefish (*Champsocephalus gunnari*) off the Kerguelen islands (arrow indicates the EEZ establishment).

highest catches of mackerel icefish have always occurred on the north-eastern shelf, probably because higher abundance of zooplankton allowed higher biomass of the stock. The cyclic landings of mackerel icefish have followed the periodic recruitment of strong cohorts (Figs 8 and 11) but the fishing pressure has probably been too high along the

series reducing the cohorts strength from one cycle to another as observed from cohort analysis (Fig. 12) (Duhamel and Agnew, 1990). A declining trend in numbers at age led to the closure of the fishery in 1995. Recent biomass survey (2006) showed a low biomass status of < 5 000 t (Duhamel and Hautecoeur, 2009). Changes could rapidly occur though,

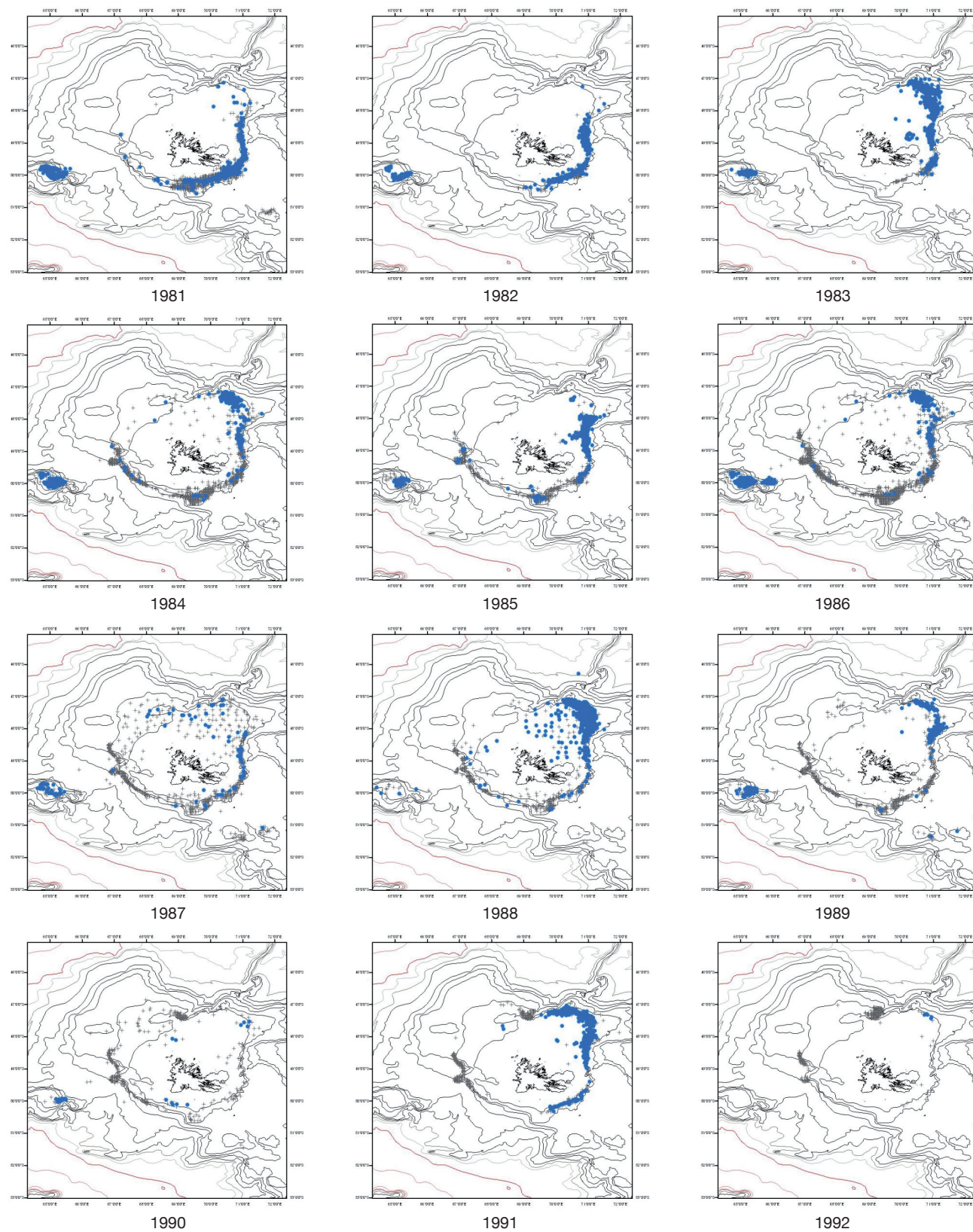


Figure 11. - Positive trawl catches of mackerel icefish (*Chamsocephalus gunnari*) from 1981 to 1995 both on the shelf and Skif bank (SW) in the Kerguelen Islands EEZ.

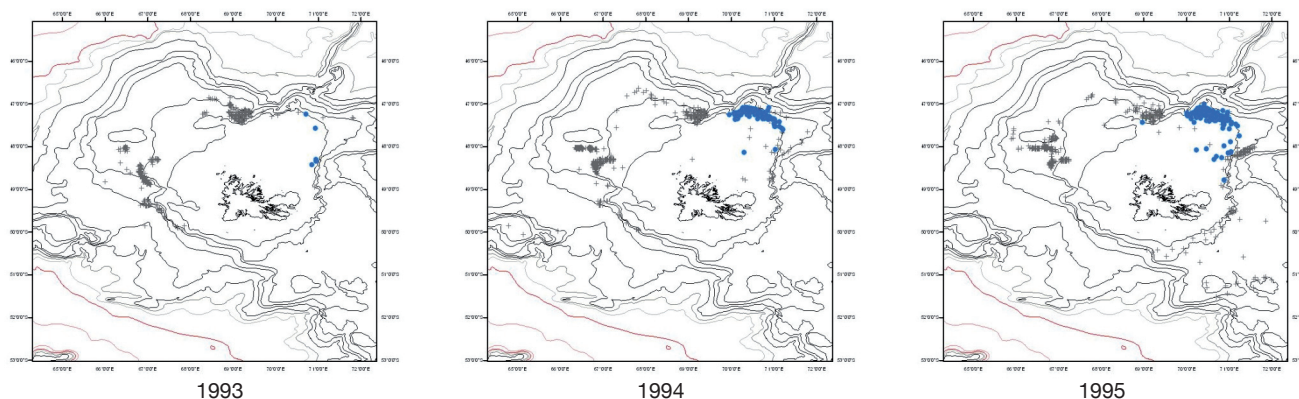
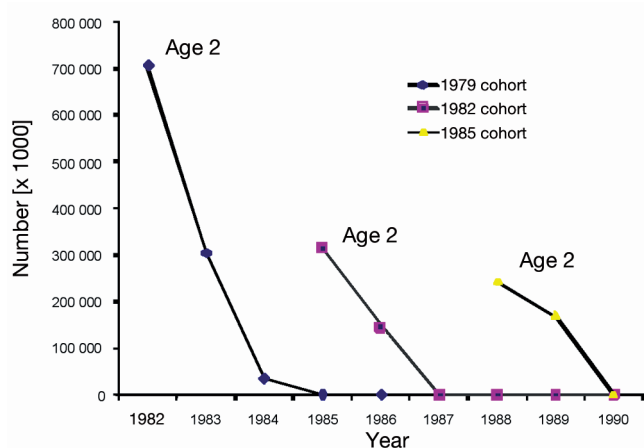


Figure 11. - Continued.

Figure 12. - Cohort analysis for mackerel icefish (*Champsocephalus gunnari*) Kerguelen Islands shelf stock from 1982 to 1990 (from Duhamel and Agnew, 1990).

as observed around Heard Islands where the population and catch limits follow cyclic trends in cohort biomass (Welsford, 2010).

The cohort strength relationships are still not clear but probably related to plankton abundance driving the body condition and success in spawning and/or hatching. The El Nino Southern Oscillation (ENSO) events with the warming of sea surface temperatures and its effects on plankton abundance could also be an additional parameter to consider. Furthermore, the predation pressure of the recent rebuilding population of fur seals (*Arctocephalus gazella*) on the Kerguelen Islands could reduce the cohort recovery particularly in the case of a declining population. Ecosystem modelling in the shelf inshore waters, where mackerel icefish grows, needs to be explored to further study the dynamics of this species.

The Patagonian toothfish *Dissostichus eleginoides*

The species, the largest Southern Ocean teleost, reaches a maximum size of about 215 cm (> 80 kg) for a life time

of up to 35 years. The life cycle is complex and unique with an ontogenic migration from the shelf to the deep-sea (> 2500 m) (Duhamel, 1984, 1987d) (Fig. 13) and related major changes in the diet (from pelagic crustaceans to fish to cephalopods) (Duhamel *et al.*, 2005). Sperm whales seem the only regular predator of adult Patagonian toothfish. Neutral buoyancy at each depth level is possible because the body contains high levels of lipids. Tagging has revealed that this top predator can exhibit large scale geographical migrations from the Kerguelen Plateau to Crozet and the south-west Indian ridge (> 2000 km!) but the majority of the population seems resident. One meta-population is suspected in the Indian sector of the Southern Ocean. Spawning of adult stock occurs during winter at the Kerguelen Islands on the western slope and banks. Hatching matches with spring plankton bloom and fingerlings settle during summer on shallow shelf. Growth up to 10 cm/year is observed during the first years of life. When maturity has been reached (6-7 years for males 9-10 years for females at about 60 and 90 cm in size, respectively), fecundity is reported to be the highest among the Notothenioids (Duhamel *et al.*, 2005). Jellymeat fish are sometimes found in the adult catches without clear explanation to this phenomenon.

The Patagonian toothfish has been unexploited till 1984/85, scarcely reported as by-catch before, but depletion in the mid 1980's of the shelf/slope species led the scouting trawlers of the USSR to seek new resources. First fishable aggregations were found in the western deep-sea part of the shelf drop and later in northern and north-eastern deep-sea hot-spots (submarine canyons). Longline allowed the fishery to spread off the slope and now all the fishing grounds are known. The fact that the stock has been recently discovered, and when EEZ was in force, has helped to promote early management. Legal catches have always been regulated with specific conservation measures (minimum size of landed catch, shallow water prohibition of the fishing activities, area closures). It is the only fish species of significant biomass detected in the 1987-1988 surveys for which the recent 2006 survey still showed a sig-

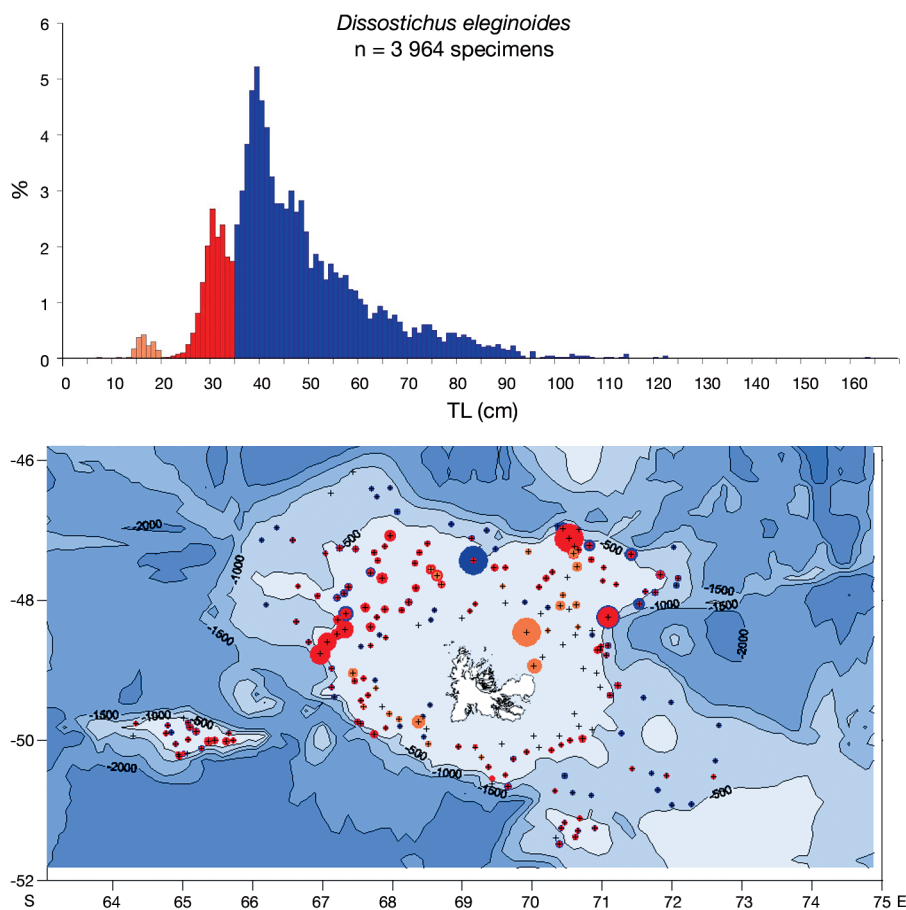


Figure 13. - Ontogenic migration of Patagonian toothfish (*Dissostichus eleginoides*) at Kerguelen Islands revealed by proportion of size classes in LFD analysis during the POKER biomass survey (2006) (pink, red and blue circles correspond to the first, second and third modal peaks of the POKER cruise in the total LFD (upper box)).

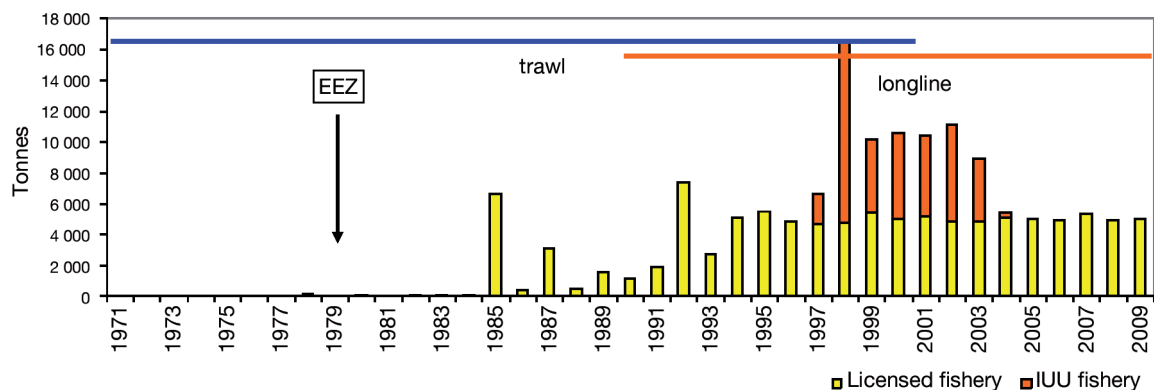


Figure 14. - Total catches of Patagonian toothfish (*Dissostichus eleginoides*) in the Kerguelen Islands EEZ. The fishing method (trawl or longline) is specified. The IUU catches have been estimated during the 1977-2004 episode.

nificant biomass estimated at 150 000 t (Duhamel and Hautecoeur, 2009), both on the shelf and in the deep-sea despite an IUU episode. Such event which occurred from 1997 to 2005 (Duhamel, 2003) in the EEZ before being weeded out (Fig. 14), was a consequence of the fast-increasing market value of the Patagonian toothfish by the end of the 1990's. Preliminary modelling (using the CCAMLR model CASAL, Bull *et al.*, 2005) showed that the CCAMLR criteria for a sus-

tainable exploitation is enforced with the present level (about 5 000 t) of annual catches using deep-sea longliners. Indices of abundance using catch per unit effort (CPUE) of longliners have initially shown a drop, which is probably related to overfishing and the cumulative effect of legal and illegal fishing (Lord *et al.*, 2006). This was followed by a stable period when illegal fishing was abolished, which eventually lead to the recent progressive increase in yields (Fig. 15).

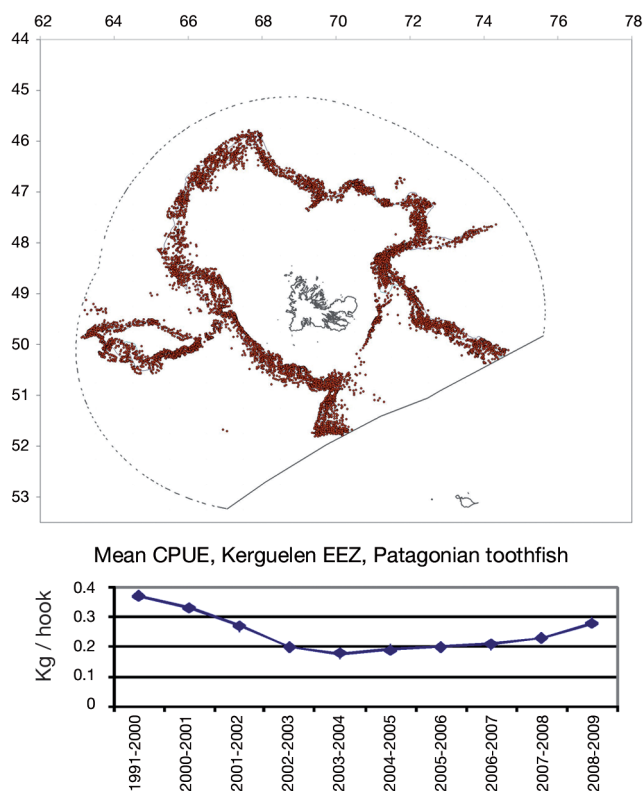


Figure 15. - Fishing grounds covered by longliners in the Kerguelen Islands EEZ and their mean annual indices of abundance (CPUE in kg/hook) for Patagonian toothfish (*Dissostichus eleginoides*) catches from 1999-2000 to 2008-2009.

Some questions need to be resolved in the future for a better fit in the models. The first is the stocks' relationships with the Kerguelen Plateau itself (including Australian fishery targeting Patagonian toothfish around Heard Island) and outside (Crozet, Marion/Prince-Edward and SW Indian ridge to the east) to evaluate the real extent of interaction between stocks. Tagging experiments are expected to provide answers. The second is the necessity to improve growth validation because otolith reading is quite difficult and can lead to misinterpretation in ageing and eventually introduce errors in models. The annual proportion of spawners in the adult stock is finally an important biological parameter useful to fit the models for the management of the fishery.

CONCLUSION AND PERSPECTIVES

Stability in the fish distribution, both spatially and bathymetrically, over the shelf, banks and deep-sea area of the Kerguelen Islands is one of the characteristics of the populations, fished and unfished. Following longline fishery in the deep-sea, sustainable fishery off the Kerguelen Islands has only been achieved for the Patagonian toothfish after 40 years of exploitation (initially without any management,

then the declaration of the EEZ and the establishment and development of conservation measures by CCAMLR). The 2006 biomass (Duhamel and Hautecoeur, 2009) of mackerel icefish and marbled notothen seems to be too low to re-open two of these historic trawl fisheries. However, with the obtained knowledge from a more regular monitoring of the stocks, the short-living species mackerel icefish could provide, some years of sustainable fishery from abundant incoming cohorts as observed in the other neighbour Plateau fishery on the Heard Islands shelf. The upward trend in the biomass of grey notothen allows optimism for this stock. Such a situation is in contrast with the present scenario on the South Georgia shelf, the other major fishing grounds of the Southern Ocean, where only Patagonian toothfish and mackerel icefish are still exploited.

Further, regular biomass surveys are needed to calibrate models (CASAL and towards Stock Synthesis 3); more study of recruitment pattern of mackerel icefish and Patagonian toothfish is needed. Cooperative work on ageing validation, tagging, ecosystem relationships (fish by-catch, benthos impact of gears, birds and sea mammals incidental fishing mortality) are necessary to adjust conservation measures and to test management options with regards to the national and CCAMLR objectives. An ecosystem model for the Kerguelen Plateau, as tentatively developed for the Kerguelen Islands EEZ (Pruvost *et al.*, 2005), is an objective to pursue. It can help the conservation of the most vulnerable stocks and provides opportunity to consider marine protected areas.

Acknowledgements. - We thank the fishery observers for the difficult job conducted on board the fishing vessels, the assistance of masters, crew and the Terres Australes et Antarctiques Françaises (TAAF) fishery team (service COPEC). Grants from Fisheries Direction (Ministry of Agriculture and Fisheries) have been received for regular monitoring of the fishery since the EEZ establishment. Cooperative work with shipowners has allowed the validation of collected data; their support to the scientific surveys is appreciated.

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